HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS PROGRAM

PROJECT PLAN

FOR THE

NASA RESEARCH AND EDUCATION NETWORK (NREN) PROJECT

June 2000

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NASA RESEARCH AND EDUCATION NETWORK (NREN)

PROJECT PLAN

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NASA RESEARCH AND EDUCATION NETWORK (NREN)

PROJECT PLAN

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1. INTRODUCTION

1.1 Purpose

This NASA Research and Education Network (NREN) Project Plan describes the implementation of the NASA NREN Project. This plan defines the NREN objectives, technical approach and management plan. This plan also reflects NREN's strategies to complete the Program commitments identified in the High Performance Computing and Communications (HPCC) Program Plan dated April 2000. When approved, this NREN Project Plan will serve as the basic agreement between the NASA HPCC Program and the NREN Project.

1.2 Overview

The goal of the NASA Research and Education Network Project is to:

"Extend United States technological leadership in computer communications through research and development that advances leading edge networking technology and services, then apply these enhanced capabilities to NASA mission and educational services."

The NREN vision is to enable the fusion of emerging network technologies into NASA mission applications. NREN will realize its mission by researching, developing, and demonstrating advanced networking technologies, thus enabling new methodologies for achieving NASA science, engineering and education objectives. NASA missions will reap exciting benefits from interactive visualization, enhanced data sharing, distributed collaboration and remote instrumentation capabilities.

NREN provides a next generation network testbed to serve as a platform for prototyping and demonstrating new applications that stress current network capabilities. In addition, NREN will work with the NASA Integrated Services Network (NISN) to transfer new networking technologies to NASA operational networks.

The NREN Project is NASA's primary contribution to the Federal Next Generation Internet (NGI) initiative. NREN serves the NASA community under the NGI umbrella. As part of the Federal Computing, Information and Communications (CIC) R&D Large Scale Networking (LSN) Working Group, the main goal of NGI is to assure continuing U.S. technological leadership in communications through research and development that advances the leading edge of internetworking technologies and services. The NGI initiative is a multiagency Federal partnership with industry and academia to develop significantly higher performance networking technologies and systems enabling next-generation distributed applications between scientists, engineers, and computing resources. The NGI initiative

promotes experimentation with the next generation of networking technologies, and demonstrates new applications that meet important national and agency goals.

2. OBJECTIVES

NREN's primary project objective is to infuse emerging network technologies into NASA mission-critical applications. To meet this customer-impact objective NREN must achieve advances in network performance, interoperability, portability, reliability, resource management, and customer usability. Specific technical objectives in these areas are described in Sections 2.2 - 2.7 below.

Performance goals and performance indicators are associated with each of the customer-impact and technical objectives. The objectives will be met if all of the indicated performance goals are met. The performance indicators suggest ways of measuring the progress that is being made towards meeting the performance goals.

2.1 Customer Impact Objective

Infuse emerging networking technologies into NASA mission-critical applications.

Performance Goals

Demonstrate or document the use of HPCCP technologies to support the reduction in the design cycle time of at least five NASA or NASA-sponsored design events, from at least four distinct NASA Programs, contributing directly to the Aerospace Technology Enterprise goals.

Demonstrate or document the use of HPCCP technologies to enable the analysis or simulation, as appropriate, of three distinct elements of the National Air Space contributing directly to the Aerospace Technology Enterprise goals.

Demonstrate or document the use of HPCCP networking technologies to enable the implementation or development of four projects/programs directly supporting the NASA Earth and space science research objectives.

Performance Indicators

- Industry and NASA baseline metrics
- Infusion of HPCC Program technologies and applications into NASA communities
- Incorporation of HPCC technology into NASA spacecraft and aircraft platforms

2.2 Communications Performance Objective

Dramatically increase communications performance available for use in meeting NASA mission requirements.

Performance Goals

Demonstrate the effective use on NASA aerospace systems, Earth and space sciences, or education challenges of communications systems delivering 1 gigabit/second end-to-end sustained, ground-based throughput.

Demonstrate measurement of network flows with multiple service levels.

Performance Indicators

- Performance analysis and monitoring tools
- Implementation of new networking technologies and capabilities
- Use of revolutionary application across Next Generation Internet

2.3 Interoperability Objective

Dramatically increase the interoperability of application and system software operating on high-performance computing and communications systems available for use in meeting NASA mission requirements.

Performance Goals

Demonstrate on NASA aerospace systems, Earth and space sciences, or education challenges technologies that enable:

- High-performance multicast protocols among five networks, and quality-of-service and traffic engineering capabilities among three networks.
- Integration of a new networking protocol, methodology or tool into an integrated testbed in one day.

Performance Indicators

- Industry-standard software design and coding practices
- Configuration management and interface agreements

2.4 Portability Objective

Dramatically improve the portability of application software and data to new or reconfigured high-performance computing and communications systems available for use in meeting NASA mission requirements.

Performance Goals

Demonstrate on NASA aerospace systems, Earth and space sciences, or education challenges technologies that enable:

- Successful execution of a computational simulation, data analysis, communication, or other tool on a new computer, network, or storage system, or combination of these resources within one week.
- Successful execution of a computational simulation, data analysis, communication, or other tool on a computer, network, or storage system, or combination of these resources within one day of a modification in the software or hardware configuration of these resources.

Performance Indicators

- Use of software engineering techniques
- Communications protocol reusability

2.5 Reliability Objective

Dramatically improve the reliability of user-requested events executing on high-performance communications systems available for use in meeting NASA mission requirements.

Performance Goals

Demonstrate on NASA aerospace systems applications the successful execution of 99% of the user requested computational events over a 24-hour time period on a distributed computational system including at least ten distinct resources, including at least one computer platform, and one wide-area network.

Performance Indicators

Network path redundancy

2.6 Resource Management Objective

Dramatically improve the ability to manage heterogeneous and distributed high-performance networking resources available for use in meeting NASA mission requirements.

Performance Goals

Demonstrate on NASA aerospace systems, Earth science, and space science applications the ability to allocate compute, storage, and network resources to a requested computational event, including at

least ten distinct resources, including at least one computer platform, and one mass storage system, and one wide-area network.

Performance Indicators

- Fielding of applications capable of effectively exploiting distributed resources
- Distribution of software to enable simple and timely allocation of resources
- Identification of a networking resource pool which can be allocated

2.7 Customer Usability Objective

Dramatically improve the usability of high-performance computing and communications tools and techniques available for use in meeting NASA mission requirements.

Performance Goal

Provide the integration of networking enhancements into aerospace and Earth sciences applications codes that allow for a quantifiable improvement in user perceived performance.

Performance Indicators

- Usability testing
- Identification of specific usability requirements
- Development of software modules or systems to enhance usability

3. CUSTOMER DEFINITION AND ADVOCACY

The NREN Project enables the development of new applications and new paradigms for conducting science across all NASA Enterprise Programs. Working closely with NASA Programs, NASA centers and other Federal agencies, NREN selects applications that are constrained by currently available network capabilities. NREN then works with NASA mission personnel to develop and demonstrate these applications, researching network technologies that are required to bring the applications to fruition.

NREN will focus on facilitating advances in six network technology areas: multicast, Quality of Service (QoS), gigabit networking, hybrid networking, adaptive middleware, and traffic engineering. NREN's strategy to integrate advanced networking technologies with stressing applications is outlined below:

- Evaluate emerging network technologies that promise to enable future NASA applications
- Architect the NREN testbed, a leading-edge, high-bandwidth network connecting HPCC and other targeted NASA application communities
- Prototype selected technologies using the NREN testbed
- Prototype next-generation NASA applications on the NREN testbed, using the advanced technologies, and validate successful approaches

- Collaborate with other Next Generation Internet or Internet2 high-performance testbeds as appropriate

Specific NREN customers are other NASA Programs and organizations, other U.S. Government Agencies, NASA-sponsored university researchers, the U.S. education community, and the information technology industry. NREN applications are selected and prototyped in close collaboration with our customers; a discipline point of contact is identified for each application to work closely with an NREN point of contact. Selection criteria include substantial impact on NASA missions and demonstrable advancement of the current state of the art in networking technology. The table below lists current application activities within NREN, the targeted NASA Enterprise or Office customer, and the technical area that provides the primary challenge in implementing the application. Other applications will be added as the NREN Project progresses.

NREN regularly interfaces with its customer base via hosting yearly NREN workshops that bring together government, industry, and academic networking experts; meeting frequently with personnel representing the various NASA Enterprises; presenting papers at technical workshops and conferences; and demonstrating applications at high-performance computing conferences, other national and international conferences, and other appropriate forums. The NREN Project, along with activities sponsored by the other NGI agencies, is periodically reviewed by the President's Information Technology Advisory Committee (PITAC).

Advocacy for the NREN Project within NASA is led by the HPCC Program, with support from the Aerospace Technology, Earth Science, and Space Science Enterprises. Advocacy on the Federal level is led by the Large Scale Network (LSN) Working Group. The LSN serves as the primary vehicle for interactions with the PITAC. NREN interacts with other NGI and Internet2 testbeds by participating in the Joint Engineering Team (JET), High Performance Network Application Team (HPNAT), and Network Research Team (NRT) within the LSN. NREN also interacts directly with the Internet2 community.

Table 1-Targeted NASA Customers

NREN Application Activities	Targeted NASA Enterprise Customers	Technical Area
Meta Data Catalog/ Storage Resource Brokers	Aerospace Technology	Gigabit networking
Remote Aviation Help Desk	Aerospace Technology	Gigabit networking/ Adaptive middleware
Virtual Wind Tunnel	Aerospace Technology	Quality of Service
Digital Earth/Sky	Earth Science/Space Science	Gigabit networking
Distribution of Large Data Sets	Earth Science/Space Science	Multicast
Clock & Data	Earth Science	Quality of Service
Trans-Pacific Demonstrations	Earth Science	Hybrid networking
Shuttle Radar Topography Mission	Earth Science/HEDS	Hybrid networking
Video Streaming	HEDS	Multicast/ Quality of Service
Education Outreach/ Teleseminars	Office of Human Resources and Education	Multicast
Interplanetary Internet	Space Science	Hybrid networking
Virtual Mars	Space Science	Gigabit networking
Molecular Modeling	Space Science	Gigabit networking
Digital Video over IP	Space Science	Multicast
Electron Microscopy	Space Science	Quality of Service/ Adaptive middleware
Mars Rover	Space Science	Quality of Service

4. PROJECT AUTHORITY

The overall project authority is established by the Program Commitment Agreement (PCA) through the HPCC Program Office and the NASA Headquarters Program Management Council (PMC). The Program Commitment Agreement (PCA) represents the Agency-level agreement for the implementation of the HPCC Program. The overall management of the NREN Project is the responsibility of the NREN Project Office at Ames Research Center (ARC). In addition to lead center activities at ARC, supporting centers to the NREN Project include Glenn Research Center (GRC) and

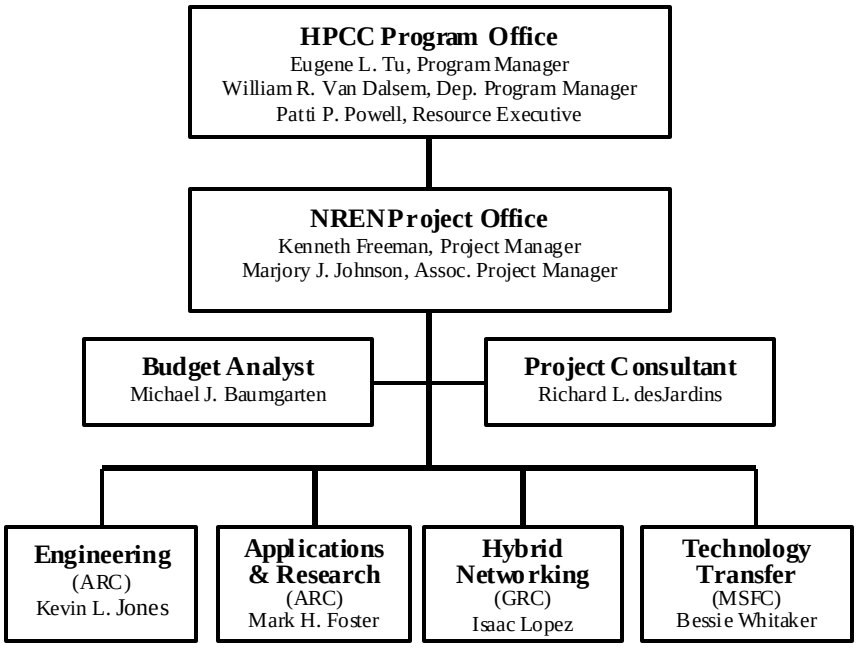
Marshall Space Flight Center (MSFC). The Change Log listing changes to the Project Plan appears in Section 22.

5. MANAGEMENT

5.1 Organization and Reporting

The NREN Project receives programmatic guidance from the HPCC Program Office. An overall organizational chart is listed below.

Table 2-Project Management Structure



5.2 Project Manager Responsibilities

Consistent with the strategic direction of the project given from the HPCC Program Manager, the Project Manager provides the overall management of the NREN project and ensures NREN meets the goals of the program. Moreover, the project manager has a responsibility to participate as part of the program management team, providing information and assisting the program manager in the execution of the integrated program. Furthermore, through delivered products, the project manager is responsible for the Project success pertaining to implementation and customer satisfaction. Also, the project manager is responsible for safety, cost, schedule, and technical performance of the project.

The Project Manager oversees preparation of the Project Plan, which is then submitted to the HPCC Program Manager. Furthermore, through the HPCC Program Manager, the Project Plan is submitted to the Director of Ames Research Center. The Project manager oversees the multi-center Project and ensures performance of Project milestones which contribute to HPCC Program milestones. This

performance is reported to the Director of Ames Research Center through the HPCC Program Manager. The Project Manager provides guidance, coordinates with the customers of the project and suggests strategic investment strategies.

5.3 Associate Project Manager Responsibilities

As delegated by the NREN Project Manager, the Associate Project Manager's responsibilities include, but are not limited to general support of the Project Office and NREN collaboration with academia, industry and other federal agencies. These responsibilities are discharged by the NREN Associate Project Manager with assistance from the NREN staff and related performing organizations.

5.4 Network Engineering

The Network Engineering Group is responsible for network architecture, technology development, testbed management and network implementations. The NREN Engineering Group Lead is responsible for managing these tasks and coordinating activities with the NREN project office and other NREN groups. The Engineering Group is led from Ames.

5.5 Network Applications and Research

The Network Applications and Research Group is responsible for application demonstrations, software development and applied research. The NREN Applications and Research Group Lead is responsible for managing these tasks and coordinating activities with the NREN project office and other NREN groups. The Applications and Research Group is led from Ames.

5.6 Hybrid Networking

The Hybrid Networking Group is responsible for researching, developing, and demonstrating non-terrestrial networking technologies. The Hybrid Networking Group Lead is responsible for managing these tasks and coordination with the NREN project office and other NREN groups. The Hybrid Networking Group is led from Glenn.

5.7 Technology Transfer

The Technology Transfer Group Lead is responsible for assisting in integrating NREN applications and technologies into production environments. The Technology Transfer Group Lead is responsible for managing these tasks and coordination with the NREN project office and other NREN groups. The Technology Transfer Group is led from Marshall.

5.8 NASA External Internetworking

Coordination among the Federal agencies and with the academic and industrial communities is essential to the success of the NREN Project. NREN coordinates its Federal CIC R&D project role through participation in the Large Scale Networking (LSN) Working Group and its associated teams. The

NREN project office collaborates with the LSN sister agencies, NSF, DOE, DARPA, National Institute of Standards and Technology (NIST), and the National Institutes of Health (NIH), as well as non-Federal Internet coordination organizations including Internet2 and Internet Engineering Task Force (IETF). NREN will continue its support through partnering with the Federal HPCC networking members in an outreach collaboration program with industry and universities. Overall coordination of Federal agency programs supporting the NCO IT R&D Program is the responsibility of the Office of Science and Technology Policy through the National Coordination Office.

6. TECHNICAL SUMMARY

The focus of NREN is to enable next-generation NASA networking applications. NREN has identified several NASA missions and applications that are constrained by the current state of the art of network technologies, and has determined that the following emerging technologies will significantly benefit these applications: multicast (including reliable multicast), Quality of Service (QoS), gigabit networking, hybrid networking, adaptive middleware, and traffic engineering. NREN will evaluate alternative approaches to implementing these technologies and will prototype solutions in the context of specific NASA applications.

6.1 Multicast

Multicast, point-to-multipoint transmission, is the primary technology that enables collaborative applications. Multicast was initially introduced into the Internet by creating virtual multicast tunnels within the unicast infrastructure. Tunneling, however, is only an interim solution, as it is extremely inefficient. NREN is taking the lead in deploying native multicast in wide area networks, thus enabling very high bandwidth multicast.

Multicast is inherently unreliable transmission, since it is based on the unreliable UDP (User Datagram Protocol) transport protocol. While most audio and video transmissions are tolerant of a small level of packet loss, file transfer and imaging applications typically are not. Reliable multicast is required for these latter activities, i.e., native multicast must be augmented by appropriate mechanisms to add reliability. Different strategies for achieving reliable multicast have been proposed, including the use of forward error correction; NREN will evaluate the strengths and weaknesses of these strategies in the context of specific NASA applications.

NREN has successfully demonstrated the use of native multicast across multiple wide-area network domains to support the Virtual Collaborative Clinic application. In the future NREN will demonstrate the use of multicast to support efficient distribution of large data sets for Earth and Space Science, video streaming for Human Exploration and Development of Space, digital video over IP for Space Science, and education outreach for the Office of Human Resources and Education. The focus in these demonstrations will be on achieving multicast rates greater than 50 Mbps to the end user and on achieving reliable data transfer to heterogeneous receivers. NREN is currently working with NASA Integrated Services Network (NISN) personnel to provide instruction and guidance on deployment of native multicast on NASA operational networks.

6.2 Quality of Service

QoS technologies address the commitment of resources to specific applications to ensure that values of such performance parameters as bandwidth, latency, jitter, and packet loss stay within an acceptable range. The ability to provide QoS to end-user applications will enable efficient sharing of network resources among multiple users, while providing preferential treatment to selected applications when network resources become scarce. NREN will investigate various approaches to QoS, including shaping traffic as it enters the network, reserving network resources, utilizing different queuing strategies within the routers, and labeling selected network flows and then providing preferential treatment to those flows within the network backbone (e.g., DiffServ).

In particular, NREN is analyzing the performance of ATM QoS mechanisms and IP router queueing mechanisms using the NREN internal lab facilities. NREN is also participating in the broader Internet2 university community to develop the QBone, an experimental wide-area QoS testbed. The objective of the QBone is to develop a DiffServ environment across multiple wide-area network domains. An initial focus is experimentation to determine how to support a service class called Abilene Premium Service by utilizing Expedited Forwarding per-hop behavior in testbed routers.

NREN is currently working with Argonne National Laboratory (ANL) to develop and test the Globus Architecture for Reservation and Allocation (GARA). GARA enhances the Globus software infrastructure being developed by ANL and the University of Southern California's Information Sciences Institute by providing mechanisms to enable advanced reservation of network bandwidth. NREN will conduct testing of GARA between the NREN lab and a testbed at ANL. NREN plans to demonstrate the utility of GARA to support distributed supercomputing applications between NASA centers and other government labs.

NREN is also developing a network monitoring and management tool called PCMON to support detailed analysis of IP packet flows. Current monitoring and management mechanisms assess the overall connectivity of the core network but do not provide insight into application-specific performance and are not flexible enough for short-term measurements that are limited to the scope of particular connections. NREN will incorporate both passive (e.g., data stream sampling) and active measurement techniques, such as traffic generators and collectors at particular endpoints, into PCMON. PCMON will enable relative performance (bandwidth utilization, latency) measurement between competing IP traffic flows as well as the more traditional measurements of performance on an end-to-end basis and in the core network.

6.3 Middleware

NREN will prototype network technology to enable the creation of a middleware-enhanced internetwork to support a very high-performance geographically distributed heterogeneous information and computational capability. The middleware will address scheduling and other QoS issues as well as security issues. Such a platform has the potential of transforming NASA missions in the 21st century.

NREN will work with university partners to develop adaptive middleware to support multimedia applications. By providing an interface between an application and system resources, adaptive

middleware will enable an application to communicate its requirements to the underlying computer and networking system (both in terms of computational resources and network resources), the system will be able to respond to resource requests, and both the application and the system will be able to adapt to changing status while the application is running.

A middleware control architecture for distributed multimedia applications (Agilos), developed at the University of Illinois under partial funding by NREN, has been validated on a distributed visual tracking application. Future plans are to demonstrate the benefits of Agilos on a specific NASA application, such as the Remote Aviation Help Desk to support Aerospace Technology or Electron Microscopy to support Astrobiology/Space Science.

6.4 Gigabit Networking

Several NASA Enterprise Programs are developing applications that will involve interactive visualization of large data sets; these applications will require ultra-high-bandwidth network connections. To support these applications, NREN will connect to the National Transparent Optical Network (NTON), a 10+ gigabit/second optical network on the west coast. In turn NTON connects to the Advanced Technology Demonstration Network (ATDNet), a comparable network in the Washington, D.C. area, via the High Speed Connectivity Consortium (HSCC) 2.5 gigabit/second network. This networking infrastructure will enable end-to-end gigabit connectivity between selected NASA sites and application partners across the country. NREN will collaborate with Federal Agency and university partners, utilizing the above networking infrastructure, to prototype digital-imagery applications for Earth/Space Sciences.

NREN is currently planning to host a workshop entitled "Gigabit Networking: The End-to-End View" in August 2000. Emerging high-bandwidth (hundreds of Mbps) applications will be demonstrated, each accompanied by a lessons-learned presentation. The objective of the workshop is to develop a set of gigabit technology roadmaps (covering the areas of connectivity, desktop platform, application integration, and security) leading to the demonstration and measurement of applications that require at least 500 Mbps end to end. NREN will then work with its NGI and Internet2 partners to achieve the milestones identified in these roadmaps.

6.5 Hybrid Networking

Many NASA applications require access to remote sites or to sites that do not have high-speed terrestrial connectivity. To support such applications, a combination of satellite and terrestrial networks must be used. NREN will work with NASA Glenn Research Center personnel and with commercial satellite partners to enable high-performance NASA mission applications over hybrid networks. NREN is currently working with the international Earth Science community to demonstrate hybrid applications between the U.S. and Japan and between the U.S. and Germany.

Traditional network protocols (designed and tuned for terrestrial networks) may require modification to enhance performance in the high-latency, lossy hybrid network environment. Under an NREN grant, Georgia Tech is developing some TCP/IP protocol modifications for hybrid networking. With support

from Consolidated Space Operations Contract (CSOC) personnel, software implementations of some of these protocols are currently being tested using the NASA Advanced Communications Technology Satellite (ACTS).

6.6 Traffic Engineering

Traffic engineering is a natural follow-on to NREN's Quality of Service activities. The objective of traffic engineering is to enhance network performance by distributing traffic evenly across network resources. Specific traffic-engineering capabilities which NREN will investigate include assigning traffic to specific network routes, providing rapid traffic adaptation to changes in network topology, and incorporating administrative policies in the routing process. These traffic-engineering capabilities will enable more efficient utilization of system resources. This translates into improved services, in terms of both increased throughput and reduced delay, for NASA applications.

6.7 Other Technologies

Other network technologies are certain to emerge during the time span of this project plan. NREN will evaluate other emerging network technologies and new paradigms for collaborative interactions as they arise, and prototype these technologies as it is deemed appropriate.

7. SCHEDULES

The table below represents NREN's contribution to the HPCC milestones as well as its corresponding metric and schedule.

Table 3-NREN Contributions to Program Milestones

PCA Program Milestone	NREN Project Milestone	NREN Metric	Schedule
PCA-1: Develop Component Technologies for Performance			**09/01**
1.1 Establish high-performance testbed for application performance	NR-1.1.1 ARC connected to support WAN gigabit testbed	Integrate hardware to provide gigabit WAN capability between 2 locations.	07/00
	NR-1.1.2 Performance testing confirming gigabit WAN capability at 3 locations	Integrate hardware to provide a communications testbed for HPCC applications at 3 locations with gigabit WAN capability.	09/00
1.3 Develop and apply technologies to measure and enhance performance on high-performance testbeds	NR-1.3.1 Demonstration of measurement of preferential flow in the lab environment	Quality of Service data collection tool capable of measuring 2 service classes	06/00
	NR-1.3.2 Demonstration of measurement of preferential flow across the WAN environment	Automated Quality of Service data collection tool capable of measuring multiple service classes and scalable to at least 5 nodes.	09/00
	NR-1.3.3 Insert multicast capability into 1 application involving distribution of Earth science data	2X performance in 1 application through the integration of networking enhancements into application codes.	03/01
	NR-1.3.4 Insert multicast capability into 1 application involving collaborative aerospace application	3X performance in 1 application through the integration of networking enhancements into application codes.	09/01

PCA Program Milestone	NREN Project Milestone	NREN Metric	Schedule
PCA-2: Develop component technologies for reliability and resources management			**06/03**
2.2 Develop embedded tools and services for autonomous resource estimation/ request of local and distributed ground-based systems	NR-2.2.1 Develop network resource management tools to provide QoS guarantees for 1 HPCC Application	Quality of Service guarantees based on resource management for 3 network nodes.	01/01
	NR-2.2.2 Develop mechanisms for adaptive networking capability via application resource management.	5 Mbps throughput improvement in 1 application with embedded capability to automatically estimate network resources.	09/01
	NR-2.2.3 Develop network resource management tools to provide QoS guarantees for 3 HPCC applications	QoS guarantees based on resource management for 5 network nodes.	06/02
	NR-2.2.4 Demonstrate throughput improvement in 3 applications utilizing adaptive networking capability	50 Mbps throughput improvement in 3 applications with embedded capability to automatically estimate and request WAN resources.	12/02

PCA Program Milestone	NREN Project Milestone	NREN Metric	Schedule
PCA-3: Develop component technologies for interoperability and portability			**09/03**
3.2 Interoperable and portable networking technologies	NR-3.2.1 Document current NGI network multicast status and provide instruction and guidance on deployment of native multicasting	Provide documented native multicasting implementation guide to NASA's operational networks	06/00
	NR-3.2.2 Deploy prototype QoS mechanisms in the WAN environment	QoS mechanisms implemented between 2 test facilities.	12/00
	NR-3.2.3 Demonstration of native multicast among NGI networks	Native multicast implemented across 5 NGI networks	09/01
	NR-3.2.4 Deploy prototype traffic engineering mechanisms in WAN environment	Traffic Engineering mechanisms implemented between 3 test facilities.	03/02
	NR-3.2.5 Deploy QoS capabilities within the NGI networks	Establish QoS capabilities among 3 NGI networks	09/02

PCA Program Milestone	NREN Project Milestone	NREN Metric	Schedule
PCA-5: Demonstrate integrated HPCC technologies			**09/02**
5.6 Demonstrate end-to-end networking capabilities on NASA mission-oriented applications	NR-5.6.1 Demonstrate advanced networking techniques for relevant mission applications utilizing high-speed networking	Demonstrate 1 application at 200 Mbps end to end	09/00
	NR-5.6.2 Demonstrate advanced networking techniques for relevant mission applications utilizing gigabit WAN capability	Aggregate bandwidth of mission applications measured at 500 Mbps	03/01
	NR-5.6.3 Demonstrate advanced networking techniques for relevant mission applications utilizing QoS tools	3 applications interoperating on multiple QoS-enabled networks	09/01
	NR-5.6.4 Performance testing confirming end-to-end gigabit capability	1 Gbps demonstrated end-to-end between 2 NASA centers	09/01
	NR-5.6.5 Demonstrate advanced hybrid networking techniques for relevant mission applications	1 application demonstrated involving both terrestrial and satellite networking components	03/02
	NR-5.6.6 Demonstrate application-embedded traffic engineering techniques	1 application demonstrated with embedded techniques enabling query and efficient priority utilization	09/02

PCA Program Milestone	NREN Project Milestone	NREN Metric	Schedule
PCA-6: Demonstrate significant engineering, scientific and educational impacts from integrated HPCC technologies			**09/05**
6.1 Establish impact on Earth and Space Sciences through the demonstration of a production-ready high-performance Earth and Space Science computational simulation validated by NASA Enterprise observational mission data	NR-6.1.1 Demonstrate gigabit technologies for Earth and Space Sciences	1 Earth and Space Sciences application with gigabit technologies	09/02
	NR-6.1.2 Demonstrate QoS capability for Earth and Space Sciences	1 Earth and Space Sciences application with QoS	06/03
	NR-6.1.3 Demonstrate integrated QoS and gigabit technologies for Earth and Space Sciences	2 Earth and Space Sciences applications with integrated QoS and gigabit technologies	09/03
6.3 Establish impact on aerospace design and operations through the demonstration of integrated systems of applications, tools, services and resources which enable the high-performance execution of interoperable aerospace applications across distributed heterogeneous testbeds	NR-6.3.1 Demonstrate gigabit technologies for aerospace design	1 Aerospace application with gigabit technologies	09/03
	NR-6.3.2 Demonstrate QoS capability across multiple network domains for Aerospace	1 Aerospace application with QoS technologies	09/04
	NR-6.3.3 Demonstrate adaptive middleware technologies for Aerospace	1 Aerospace application with adaptive middleware technologies	09/05

PCA Program Milestone	NREN Project Milestone	NREN Metric	Schedule
6.4 Establish impact on NASA's education mission through the demonstration of prototype revolutionary multisensory multimedia systems for education	NR-6.4.1 Demonstrate tools to optimize network performance	1 Education application	09/04
	NR-6.4.2 Demonstrate performance enhancements achieved by utilizing integrated adaptive middleware technologies	1 Education application with adaptive middleware technologies	09/05

PCA Program Milestone	NREN Project Milestone	NREN Metric	Schedule
PCA7: Establish sustainable and wide-spread customer use of HPCC Program technologies			**09/06**
7.5 Transfer NREN technologies to NASA's operational WAN	NR-7.5.1 Deploy native multicast protocols	Integration of multicast technologies into 5 NASA operational labs	09/01
	NR-7.5.2 Deploy gigabit networking technologies across LANs and WANs	Integration of gigabit networking technologies into 5 NASA operational labs	09/02
	NR-7.5.3 Deploy QoS technologies	Integration of QoS technologies into 5 NASA operational labs	09/03
	NR-7.5.4 Deploy hybrid networking technologies	Integration of hybrid networking into 5 NASA mission applications	09/04
	NR-7.5.5 Deploy adaptive middleware technologies	Integration of adaptive middleware technologies into 5 NASA mission applications	09/05
	NR-7.5.6 Deploy traffic engineering technologies	Integration of traffic engineering technologies into 5 NASA operational labs	09/06

The table below presents a calendar year timeline for completing project milestones.

Table 4: NREN Roadmap for Completing Project Milestones

	NREN Milestones	2000	2001	2002	2003	2004	2005	2006
PCA-1	1.1.1 1.1.2 1.3.1 1.3.2 1.3.3 1.3.4							
PCA-2	2.2.1 2.2.2 2.2.3 2.2.4							
PCA-3	3.2.1 3.2.2 3.2.3 3.2.4 3.2.5							
PCA-5	5.6.1 5.6.2 5.6.3 5.6.4 5.6.5 5.6.6							
PCA-6	6.1.1 6.1.2 6.1.3 6.3.1 6.3.2 6.3.3 6.4.1 6.4.2							
PCA-7	7.5.1 7.5.2 7.5.3 7.5.4 7.5.5 7.5.6							

8. RESOURCE MANAGEMENT

The Project will be will be accomplished within the budget allocations and resources listed below. The NREN Project budget presented below is consistent with the current HPCC Program plan budget, which in turn is consistent with the President's FY2000 budget as enacted by Congress.

8.1 Funding Requirements

The NREN budget profiles for FY 2000 through FY 2006 are shown in the Tables below.

Table 5-NREN Funding Allocation Profile

	Prior Years	2000	2001	2002	2003	2004	2005	2006
HPCC NREN Project Funding	**17900**	**8000**	**3850**	**4000**	**4000**	**4000**	**3100**	**3100**

Table 6-NREN Budget by WBS by FY

	2000	2001	2002	2003	2004	2005	2006
Project Management	$773	$451	$462	$462	$446	$304	$311
Engineering	$3,122	$1,185	$1,258	$1,258	$1,389	$990	$1,091
Applications & Research	$2,329	$1,129	$1,186	$1,186	$978	$702	$619
Hybrid Networking	$725	$580	$511	$511	$506	$452	$331
Technology Transfer	$1,051	$505	$583	$583	$681	$652	$748
NREN Total	**$8,000**	**$3,850**	**$4,000**	**$4,000**	**$4,000**	**$3,100**	**$3,100**

8.2 Institutional Requirements

The civil servant workforce allocated by NASA center to the NREN Project is shown in the table below. All entries are in full time equivalent work years (FTEs).

Table 7-Direct Civil Servant Workforce Breakdown for the NREN Project

	2000	2001	2002	2003	2004	2005	2006
Project Management	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Engineering	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Applications & Research	3.5	2.5	2.5	2.5	2.5	2.5	2.5

Hybrid Networking	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technology Transfer	0.2	0.2	0.2	0.2	0.2	0.2	0.2
NREN Total	**7.0**	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**

The table below presents institutional requirements in a different format, mapping project milestones to WBS elements.

Table 8: Project Milestones per WBS Element

		Project Management	Engineering	Applications & Research	Hybrid Networking	Technology Transfer
PCA-1	1.1.1	X	X	X	-	-
	1.1.2	X	X	-	-	-
	1.3.1	X	-	-	-	-
	1.3.2	X	-	X	-	-
	1.3.3	X	X	X	-	X
	1.3.4	X	X	X	-	-
PCA-2	2.2.1	X	-	X	-	-
	2.2.2	X	-	X	-	-
	2.2.3	X	X	X	-	-
	2.2.4	X	X	X	-	-
PCA-3	3.2.1	X	-	-	-	X
	3.2.2	X	X	X	-	-
	3.2.3	X	X	-	-	X
	3.2.4	X	X	X	-	-
	3.2.5	X	X	X	-	-
PCA-5	5.6.1	X	X	-	-	-
	5.6.2	X	X	-	-	-
	5.6.3	X	X	X	-	-
	5.6.4	X	X	-	-	-
	5.6.5	X	X	X	X	-
	5.6.6	X	X	X	-	-
PCA-6	6.1.1	X	X	-	-	X
	6.1.2	X	X	X	-	X
	6.1.3	X	X	-	-	X
	6.3.1	X	X	-	-	X
	6.3.2	X	X	-	-	X
	6.3.3	X	X	X	-	X
	6.4.1	X	X	-	X	X
	6.4.2	X	X	-	X	X

PCA-7	7.5.1	**X**	**X**	-	-	**X**
	7.5.2	**X**	**X**	**X**	-	**X**
	7.5.3	**X**	**X**	-	-	**X**
	7.5.4	**X**	**X**	-	**X**	**X**
	7.5.5	**X**	**X**	**X**	-	**X**
	7.5.6	**X**	**X**	**X**	-	**X**

9. CONTROLS

The process for controlling changes of the NREN Project is described in this section.

9.1 Program and Project Changes

The Project Plan is the overall controlling document for the NREN Project. It is a contract between the NASA Project Manager and the HPCC Program Manager defining the high level requirements and commitments for the NREN Project. Moreover, the Program Commitment Agreement (PCA), the HPCC Program Plan, and the NREN Project Plan are controlled documents. The retention, updating, and approval of the Project plan is controlled as follows:

Table 9-Document Control

Document	**Retains Approved Documents**	**Preparation of Updated Documents**		**Approves Documents**
		Primary	**Supporting**	
Project Plan	Project Offices	Project Offices	Task Managers Performing Orgs.	Program Manager

Any change to the HPCC Program or the NREN Project which alters the commitments within a controlled document must be approved by the approving official(s) for all levels of documents impacted by the proposed change. The PCA, Program Plan and Project Plan include change logs which document all changes from the beginning of the HPCC Program to the date of the latest approved change.

For changes to the NREN Project within the objectives, technical scope, schedule and budgets established in the approved Project Plan, the NREN Project Manager has the authority to approve changes.

A formal process is used for managing project changes: requesting, acquiring the required level of approval, and tracking and documenting the changes. The NREN Project Office maintains the project change log, which is incorporated in the Project Plan.

Should the scope of the NREN Project require changes, whether due to resource reduction or the need to rebalance the resources within the Project, the following process will be followed. The NREN Project Manager will re-scope priorities for the overall Project. This re-scoping effort will be based upon several elements: importance to approved PCA and Program milestones; expected benefits and partner and advisory committee inputs.

Changing scope within the NREN Project requires the concurrence of the HPCC Program Manager and Lead Center Director if Project milestones are impacted. If the change in scope impacts HPCC Program milestones, then concurrence of NASA HPCC Executive Committee, composed of Associate Administrators of all of the NASA Agency Office stakeholders and chaired by the Associate Administrator of the Office of Aerospace Technology is required. Scope changes that do not impact Program or Project milestones are at the discretion of the NREN Project Manager.

9.2 NREN Networking Testbeds

Access to NREN testbeds is restricted to NASA-related research networking applications. Furthermore, the NREN testbed is not intended to provide operational services for NASA missions. The NREN networking testbeds will be utilized to research networking technologies, then transfer these technologies to production environments. Additionally, all participants of the NREN Project must comply with the NASA policies on access to software, data, and testbed facilities.

9.3 Sensitive Technology

NASA Ames, Glenn and Marshall center management, working with industry and NASA HPCC researchers, are responsible for identifying sensitive technologies. These technologies may also include proprietary data and export-controlled data. These technologies are handled in such a way that their dissemination to foreign persons, companies, laboratories, and universities is restricted. The level of restriction for various sensitive technologies will be dependent on the character of the technology.

Sensitive information that is generated under formal cooperative research agreements between NASA and non-Federal parties is protected by the amended (October 1992) NASA Space Act of 1958. Data produced under such an arrangement will be protected from Freedom of Information Act (FOIA) requests for a period of 5 years after the date of dissemination.

Negotiated License Agreements are used to restrict access to privately developed technology performed under the auspices of the NASA HPCC NREN Project. These agreements provide NASA with limited rights to use proprietary data or designs in NASA in-house or cooperative research projects. These agreements specify limits on the distribution and use of the proprietary data by NASA and NASA-licensed entities.

Some software and information developed solely within the NASA HPCC NREN Project may be subject to protection under the Export Administration Regulations (EAR) or the International Traffic in Arms Regulations (ITAR), which are export controls established by law. The participants in the NREN Project will follow applicable export control laws. These regulations establish lists or categories of technical data and/or products that may not be exported without an approved export license. (Note that the definition of "exported" includes "disclosed" and "discussed" as well as published.)

10. IMPLEMENTATION APPROACH

The NREN Project is planned, funded, managed, and executed in close cooperation with other HPCC Projects, NASA Programs, Federal agencies and laboratories, private industry, and academia to ensure that the fruits of this research project are brought into the commercial and educational marketplaces as rapidly as possible. NREN brings together a collaborative team consisting of testbed designers, systems software developers, and government and private sector network developers so that the proper balance can be orchestrated across the full spectrum of internetworking technology from hardware to applications. The project provides interim results of value to the internetworking industry by developing near-term, intermediate, and long-term technological advances that at each stage provide "end-user" benefits.

Work on the NREN Project is performed at Ames and Glenn Research Centers and at Marshall Space Flight Center by civil servants and contractors. Some work is also performed at universities under grants and cooperative agreements.

11. ACQUISITION SUMMARY

Free and open competitive procurements are used to the maximum extent possible. Interagency agreements for joint R&D endeavors and the utilization of early prototype systems will also be used. Various procurement vehicles will be used resulting in grants, cooperative agreements and contracts. Interagency agreements for joint R&D endeavors and the utilization of early prototype systems will also be used.

12. PROGRAM/PROJECT DEPENDENCIES

A critical goal of the NREN Project is to prototype end-to-end interoperability across diverse high-performance networks, thus extending the reach of NASA's research networking through an extensible internetworking architecture.

The success of the program relies heavily on partnering with NASA centers for local area networking support and collaborating with NASA programs to demonstrate revolutionary end-to-end applications. NREN has in the past existed as a network research testbed with few users in NASA. In this current NREN Project Plan, the overall goals are refocused to ensure that NASA missions directly benefit from the high performance networking technologies demonstrated by NREN.

The NASA NREN effort is conducted in close partnership with NSF, DOE, DARPA and the private sector to jointly develop and implement an interagency network architecture that meets the requirements of NASA and its federal partners. NASA's NREN approach combines existing and emerging state-of-the-art technologies to achieve an aggressive growth in performances to meet the HPCC Program objectives. Collaborative, application-oriented groups, including application scientists, systems engineers and networking technologists, work together to push the envelope of the applications, the networks, and the enhanced networking services. Once the technologies are proven in the NASA NREN environment, they are transferred to the existing NASA science and research networks, continually improving the performance of the operational networks.

12.1 NASA Internal Internetworking Relationships

Internally, there are several crucial elements of encompassing NASA internal internetworking including wide area networking, center networking support and applications partners. This is a team effort as described in the management section of this plan. Collectively this group represents the NASA Networking Community for the NREN Project.

For wide area networking, the NREN Project coordinates with three centers (ARC, GRC and MSFC). These groups in turn coordinate their efforts with the networking staffs of all of the NASA centers to implement access to NREN capabilities for wide area networking.

NREN partners with the center local area network (LAN) support groups recognizing that each center has its unique local network infrastructure to facilitate connectivity to the desktop. The NREN Project relies entirely on these networking staffs and resources of each Center for the coordination and implementation of LAN capabilities within each Center, as well as site coordination with NISN and associated Center application workgroups resulting in enabling end-to-end applications. The local LAN team is responsible to see that the network extends to the customers (the work groups on the campus—the applications areas or the missions).

The application partners are the NASA customers outlined in the Customer Definition and Advocacy section. They have the next-generation applications that require high performance end-to-end networking. The NREN team works with the applications partners to define and prototype high performance network applications demonstrations.

12.2 Partnerships with Other NGI Agencies, Internet2 Community, Universities and Industry

NREN partners with other NGI Federal Agencies and with the Internet2 community to accomplish the overall goals of the NGI initiative. NREN's primary focus within the NGI initiative is enabling NASA mission applications. Official agreements between NASA and other Federal agencies enable NASA to benefit from their NGI activities. For example, NREN benefits from the technology development funded by DARPA and from the university networks and international research internets supported by NSF. In addition, NREN partners with other agencies, such as the National Institutes of Health (NIH),

the FAA and the National Institute of Standards and Technology (NIST) to prototype applications that stress network capabilities.

NREN partners with universities by funding a modest number of research grants, targeting specific technologies that are critical to support NASA mission applications. These university-funded activities are integrated with on-site NREN activities.

NREN partners with selected companies that are leaders in the information technology industry. These industry partnerships enable NREN to influence the development of new networking technologies and to test emerging products before they become commercial.

13. AGREEMENTS

The following agreements are currently in effect:

Table 10-NREN Agreements

Agreement	Partner Name	Initiation Date	Type
Purchase Order between Regents of the Univ. of California and Sprint Communications for the ESNET Fast Packet Services	Sprint Communications	08/25/94	External/Domestic/ Commercial
Memorandum of Understanding (MOU) between NASA ARC and MSFC	MSFC	09/01/96	NASA Internal/Intra-agency
MOU between NASA Integrated Services Network (NISN) and NREN	NISN	06//01/97	NASA Internal/Intra-agency
MOU between Computing & Interdisciplinary Systems Office (CISO), Space Communications Office (SCO) at GRC, and NREN	CISO, SCO at GRC	11/01/97	NASA Internal/Intra-agency
MOU between NASA and Cisco Systems, Inc.	Cisco Systems, Inc	01/20/98 (in process of renewal)	External/Domestic/ Commercial
Permanent Best Site Agreement between FORE Systems, Inc., & NASA	FORE Systems, Inc.	02/03/98 (in process of renewal)	External/Domestic/ Commercial
Interagency Agreement (IA) between NASA ARC & National Institute of Standards & Technology (NIST)	NIST	04/27/98	External/Domestic/ Gov/Fed/Space Act/Interagency
Interagency Agreement between NASA & the Defense Advanced Research Projects Agency (DARPA)	DARPA	09/29/98	External/Domestic/ Gov/Fed/Space Act/Interagency
NASA Defense Purchase Request with the US Dept. of Energy (DOE) for ESNET Fast Packet Services	DOE	08/01/99	External/Domestic/ Gov/Fed/Space Act/Interagency
Non-disclosure Agreement for Juniper Networks, Inc., between NASA ARC and Juniper	Juniper Networks, Inc.	10/22/99	External/Domestic/ Commercial
MOU between Ames External Interface Group and NREN (internal MOU)	Ames External Interface Group	2/16/00	NASA Internal

An interagency agreement between NASA and the National Science Foundation for collaborative work on advanced networking is under negotiation.

14. PERFORMANCE ASSURANCE

This section addresses effective mechanisms for tracking and maintaining successful project performance. In delivering world class research to our customers, the NREN Project Office, Engineering and Applications Group and Research Group will follow the Ames Research Center ISO 9000 standards for performance assurance. The NREN Technology Transfer Group will follow the Marshall Space Flight Center (MSFC) ISO 9000 standards for performance assurance. Also, the NREN Hybrid Networking Group will follow the Glenn Research Center (GRC) ISO 9000 standards for performance assurance.

15. RISK MANAGEMENT

15.1 Overview

In the development of technology, risk arises from two general sources. First, the Project faces *technical risk*; that is, risk resulting from unexpected developmental difficulties. The NREN Project was planned with a portfolio of risk versus payoff. While the minimum success criteria are expected to be achieved, there are several high-risk high-payoff elements in the project. Second, the Project faces *resource/schedule risks*, which involve factors beyond the control of the NREN management and sometimes beyond the control of NASA.

15.2 Technical Risk

NASA's NREN mission requires currency with the leading edge of technology and a direction that is consistent with the future. To minimize the potential risk of investing resources in ineffective technologies, NASA frequently meets with industry and other Federal agencies to help plan the future of the technology.

Network testbeds developed under the NREN program will require innovative ideas in the full array of systems functions. To minimize the risks of systems development, NASA is a leader in interagency activities that strengthen collaborative efforts with industry and academia.

As a partner in an overall Federal program wherein high-risk research is shared by other participating Large Scale Networking agencies, NASA portions of jointly sponsored research initiatives are often dependent on funding and work commitments made by partner institutions. This risk is mitigated through cooperative planning with the other agencies to ensure a cohesive plan with no unforeseen consequences.

The Project-level technical risks are shown below.

Table 11-Technical Risk Assessment

Risk	Prob-ability	Impact	Mitigation
Customer requirements change	Medium	High	• Involve customers in the technical implementation, from concept through delivery • Design approach to adapt to customer changes • Monitor customer requirements for potential changes
Externally developed technologies and capabilities diverge from expectations	Medium	High	- Periodically assess external technology developments • Consult external experts at technical planning level • Periodically assess relevance of project milestones • Adjust technical plans at Project level • Adjust technical plans at Program level
Technical projects do not achieve performance expectations	Medium	Medium	• Schedule regular reviews of technical progress and status • Identify and leverage opportunities by redirecting technical approaches among the various activities • Document lessons learned and apply them to enhance performance of future projects
Changes in an application for one project adversely affect other NREN task elements	Low	Medium	• Facilitate task level integration and coordination
Task activities contain duplicate elements	Low	Medium	• Coordinate and integrate activities at the WBS level

To help understand and mitigate technical risk, the NREN Project is monitored on a regular basis by NASA experts and external specialists. In addition to the regularly scheduled reviews described below, the NREN Project conducts external technical peer reviews, by the President's Information Technology Advisory Committee.

15.3 Resource/Schedule Risk

The NREN test beds are a critical facility to ensure the future success of NASA's mission. To ensure the testbeds are functional for their intended purposes, NASA has invested in a diversity of technologies in multiple geographic locations that minimize natural and technical disasters. NASA also partners with other Federal agencies and industry to use their facilities when necessary.

Resource reduction is an area of relatively high risk to the NREN Project. Annually, or more frequently, the program faces budget challenges from the Agency, Enterprise, or Center levels. If necessary, NREN will de-scope project objectives in order to accommodate for resource reductions, while maintaining the overall goals of the project. De-scoping of the project goals will increase the technical risk. Furthermore, there will be an associated reduction in Technical Readiness Level (TRL). Excessive reductions in resources will require milestone changes. In extreme cases, project termination may be required.

The table below presents an overview of the overall resource/schedule risks faced by the NREN Project, their potential impact, and the mitigation actions either taken or to be taken by the Project.

Table 12-Resource/Schedule Risk Assessment

Risk	Probability	Impact	Mitigation
Reduction / loss of funding	Medium	High	• Advocate benefits to customers/stakeholders
Unavailability of major networking facilities	Low	Medium	• Develop and maintain plans for backup strategy
Partners do not meet resource commitments	Medium	Medium	• Formal MOU/MOAs • Periodic Senior Management reviews • Formal joint plans/teams

15.4 Descope Plans

In the case of resource reductions, NREN will de-scope project objectives. In order of priority, NREN will first de-scope objectives that do not have specified relationships to milestones. Next NREN will de-scope objectives that affect NREN Project milestones, but not HPCC Program milestones. Finally, if necessary, NREN will de-scope milestones that directly impact HPCC Program milestones, which will require concurrence with the HPCC Program Office and the HPCC Executive Council.

If project objectives have to be de-scoped in order to impact NREN Project milestones, the chosen milestone will be chosen based upon schedule. NREN resource reductions will be applied to milestones with the latest due date.

16. ENVIRONMENTAL IMPACT

There are no environmental impacts generated by this project.

17. SAFETY

The NREN Project encourages proper safety practices among its colleagues. All NASA civil servants, contractors and Principal Investigators are required to maintain familiarity with the NASA safety regulations. All individuals associated with NREN shall conduct their work in accordance with established regulations and with respect for their own and their co-workers' safety. NREN staff and performing organizations are expected to report any unsafe practices or unsafe conditions to their supervisor.

18. TECHNOLOGY ASSESSMENT

NREN is an internetwork research program that pursues technologies that are between five and twenty years of maturity. Applications in the areas of Earth science, space science, aerospace technologies and education are used as drivers of NREN's internetworking technology research, providing the requirements context for the work that is done.

NREN conducts TRL 2 - 6 research activities intended to prove feasibility, develop and demonstrate computing technologies for eventual introduction into NASA's operational network (i.e., NISN). In addition, NREN conducts technology outreach demonstrations that are essentially at TRL 7 - 8.

19. COMMERCIALIZATION

Commercialization opportunities will be exploited through Space Act Agreements, Cooperative Research Agreements and Memoranda of Understanding with industry. Joint projects in high risk areas will be pursued on a cost-sharing basis with industry and in close collaboration with government laboratories and academia. NASA will foster horizontal partnerships between NASA and multiple companies within the information technology sector. The NREN Project Office will also foster the vertical integration of collaborative teams between hardware suppliers, third-party software vendors, and members of the U.S. aerospace community. Lastly, the NREN Project Office sponsors and conducts technical meetings and workshops and promotes the publication of scientific and technical papers to maintain the flow of technology from NASA to industry and academia.

20. REVIEWS

The NREN Project participates in the following reviews to ensure project performance:

Table 13-NREN Review Schedule

Review Name	Purpose	Content	Timing	Reporting Requirements
Independent Annual Review	Provide validation of conformance to the PCA	Assess progress/ milestone achievement against original baseline. Review and evaluate the cost, schedule, and technical content of the program over its entire life cycle. Assess technical progress, risks remaining, and mitigation plans. Determine if any program deficiencies exist which result in revised projections exceeding predetermined thresholds.	Annual	Overview of program/project. Status and changes since the last NAR or IAR of the following: (1) Primary goals and objectives. (2) Scientific and technical objectives that drive mission requirements and implementation plans. (3) Implementation plans. (4) Progress against performance indicators and productivity measures (technical, cost, schedule).
Peer Review	Independent verification of project technical plan	Clarity of goals and objectives. Thoroughness/realism of technical plans, schedules, and cost estimates (including reserves and descoping options). Adequacy of management plans, including organizational structure and key personnel credentials. Technical complexity, risk assessment, and risk mitigation plans.	On request by PITAC	Summary report by peer review panel
Internal Project Review	Inform Project/ Program Office on Project Status	Report Highlights to NREN/HPCC Management	Quarterly (January, April, July, October)	Submission of Written Highlights in Requested form to HPCC Program Management Office

21. TAILORING

The NREN Project will be managed and implemented in accordance with the normal procedures used by the Aerospace Technology Enterprise for Systems Technology Programs. There are no major deviations from these procedures.

22. CHANGE LOG

Changes to NREN Project since inception in 1992:

- May 1997. Responded to Presidential initiative to develop NGI. Developed milestones for additional budget of $30M in FY98-00.
- December 1998. NREN Project Plan updated to comply with the revised NASA Procedures and Guidelines 7120.5A, "NASA Program and Project Management Processes and Requirements."
- May 2000. New Project milestones proposed in response to refocusing of the HPCC Program. (Refer to Appendix C for previous milestones.)

23. APPENDICES

23.1 Appendix A: NREN Accomplishments: June 1993 through December 1999

These milestones are divided into four categories: technology accomplishments, demonstrations, development of the testbed infrastructure, and administrative accomplishments.

A.1 Technology accomplishments

Interoperability

Network interoperability, Feb. - Dec. 1995: Achieved internetworking and interoperability among three independently managed high speed networks: ATDNet (DARPA), ESnet (DOE) and NREN (NASA) as part of the Information Wide Area Year (I-WAY) project hosted through Argonne National Laboratory. The resulting network infrastructure was utilized at Supercomputing '95 to support 53 nationwide applications.

ATM interoperability, March 1996: Program milestone (NR5: demonstrate interoperability between independently managed NREN networks that are based on ATM technology supplied by multiple vendors) completed on time. This is a significant accomplishment because interoperability is always a challenging issue with a new technology.

Network Exchange

Completed Program milestone NR7, Oct. 1998: "Establish next generation internetwork exchange for NASA to connect Grand Challenge universities principal investigators to NASA high performance resources."

Completed the NGIX-West exchange point design and implementation, Dec. 1998. NGIX-West has a switch-based architecture at its core, with a 10-Gbps bandwidth, providing ATM connectivity at different speeds. Several research networks, notably vBNS, Abilene, DREN, and NISN, peer with NREN and other networks at NGIX-West. NGIX-West will also partner with other networks to conduct network research primarily in the areas of Quality of Service and multicast.

Multicast

Developed the Multicast Internet Exchange (MIX) at NASA Ames, June 1998. The MIX provides a multicast-friendly peering point to handle routing between IP multicast wide-area networks. All multicast traffic to and from NASA flows through the MIX. The development of this MIX was a "first" in the internetworking world.

Submitted a Request for Comments (RFC) to the IETF titled "Multicast Friendly Internet Exchange," Nov. 1998. The RFC deals with methods of how to process multicast packets as they transit the Internet. This represents a significant contribution to sharing NREN's expertise in deploying multicast with the Internet research and engineering communities.

Completed deployment of native multicast protocols on NREN, Feb. 1999. Specific protocols included PIM-SM, BGP4+, and MSDP. Provided leadership in deploying the same set of multicast

protocols in other network domains. This accomplishment enabled the prototyping of high-bandwidth multicast applications across multiple network domains. Such applications were not feasible with dense-mode protocols or using multicast tunneling.

Engineered the network infrastructure to support a demonstration of the Virtual Collaborative Clinic (VCC) application, May 1999. The primary technical challenge for NREN was high-rate multicast, up to 32 Mbps. The VCC application used multicast to send 3-D, high-resolution stereo medical images to physicians at five widely disbursed sites.

Presented paper "Using the NREN Testbed to Prototype a High-Performance Multicast Application" by Johnson, Chew Spence, and Chao, at SuperComputing '99, Nov. 1999. This paper discussed challenges in prototyping the Virtual Collaborative Clinic application.

Quality of Service

QBone experimentation, Dec. 1998: NREN's proposal to participate in the QBone (Internet2 end-to-end QoS testbed) was accepted. The QBone testbed will be used to experiment with DiffServ technology across network domains. NREN's unique contributions to the QBone activity include extending the scope of the QBone infrastructure to NREN and the NGIX-West, evaluating the performance of DiffServ in these domains, providing applications for deployment on the QBone, and evaluating performance of these applications.

Published "QBone—Building a Testbed for Differentiated Services" by Teitlebaum, Hares, Dunn, Narayan, Neilson, Reichmeyer, in IEEE Network 9/99, Sept. 1999.

Data Distribution

Earth Science application, Nov. 1998: OhioView Phase I put in place and used to transfer files from EDC to LeRC. Phase I being transitioned to NISN. The technical objective of the OhioView application was to develop an infrastructure to distribute high-resolution multi-spectral land satellite data to a variety of users over high-performance computing networks in an affordable manner.

NREN Workshops

Project kickoff, May 1996: Hosted the HPCCP NREN Workshop. Established Ames as an Agency leader in networking technology within the HPCCP and networking communities. Policy inputs, requirements and expectations received from the community will be addressed in the NREN project plan.

Application requirements, Sept. 1997: Conducted HPCC/NREN Workshop 2 that brought together networking experts and scientists in several affinity groups to identify networking requirements to support high-performance applications within each group. Five high performance applications were demonstrated at this workshop, including Echocardiography, Nomad Rover, Mars Pathfinder Mission, Distributed Image SpreadSheet (DISS), and the Virtual Simulation Laboratory (VLAB).

Quality of Service (QoS), Aug. 1998: Attended by 100 representatives from government agencies, academia, Internet2 and industry. Eighteen papers were presented (available at:

http://www.nren.nasa.gov/workshops3.html). Many useful collaborations were initiated at this workshop.

Bridging the Gap from Networking Technologies to Applications, Aug. 1999: Co-sponsored with LSN. Networking technologists, testbed developers, and application developers discussed how to incorporate new developments in network technology into applications. The primary result of the workshop was a set of technology roadmaps that present a timeline of anticipated developments in three technology areas: QoS, advanced multicast, and security.

A.2 Demonstrations

June 1995: Program milestone (NR 3: demonstrate satellite-based gigabit applications using the ACTS satellite and associated ground terminals) completed on time.

Nov. 1995: Completed demo of ACTS between JPL and LaRC.

Dec. 1995: Supported Supercomputing '95 and show site engineering. Demonstrated the I-WAY project. In addition, demonstrated internetworking and interoperability between NREN and the Supercomputing show floor network which was provided by many vendors and carriers including Bay Networks, Fore Systems, Cisco Systems, Sprint, MCI, PacBell & TCG. Sprint provided free circuits and equipment as well as planning, engineering and provisioning support.

Jan. 1996: Completed ARIES demonstration to JPL.

Feb. - Mar. 1996: Provided demonstrations of large data set transfers across independently managed networks. Demonstrations successfully transferred satellite data between the EROS Data Center to GSFC across MAGIC (DARPA), AAI (DOD), and NREN (NASA).

June 1997: Tested the Virtual Simulation Laboratory (VLAB) over NREN which allowed engineers to participate remotely during space shuttle landing simulation in the ARC Vertical Motion Simulator.

June-July 1997: Supported telecommunications requirements for Nomad rover in Chile by creating a path for command and control data and reception of live robotic telemetry and panospheric image data with a sustained bandwidth of 1.54 Mbps for a minimum of 12 continuous hours a day.

July 1997: Provided the high-speed, determinable bandwidth connection between JPL and ARC to port image data for the virtual environment model, "MarsMap," that provided the 3-D terrain model to chart the path of Mars Pathfinder's Sojourner robot.

Aug. - Sept. 1997: Demonstrated remote Echocardiography (EC) in real-time for interactive telemedicine.

Sept. 1997: Demonstrated the Distributed Image SpreadSheet (DISS) at NREN Workshop 2 using ATM networking end-to-end to display and manipulate gigabyte-sized datasets and retrieve data files in remote sensing archives.

Nov. 1997: Provided high-performance networking support for Supercomputing97 (SC97) conference held in San Jose from November 17 through 21, the first of the SC conferences to emphasize high performance networking, distributed computing, and data intensive applications.

March 1998: Participated in Distributed Image SpreadSheet and Echocardiography applications demonstrations at the Highway 1 facility in Washington, D.C.

Nov. 1998: Successfully prototyped Turbulent Convection and Dynamos in Stars, an HPCC ESS Grand Challenge application, across several high performance wide area research networks via the NGI Exchange in Chicago. This application was demonstrated at SC '98.

Nov. 1998: Demonstrated Autogenic Feedback application. Images and data were transmitted from a patient at Lewis Research Center in Cleveland, Ohio, to researchers located at Ames over the NREN network. This was the first test of the application over a wide-area network.

February 1999: Demonstrated four Earth Science applications at the U.S.-Japan Global Observation Information Symposium and Workshop (GOIN'99) in Hawaii. This was the first substantial use of the Internet2 connection to the University of Hawaii.

May 1999: Participated in demonstration of Virtual Collaborative Clinic application in support of the NASA Ames Center for Bioinformatics. This demonstration attracted nationwide attention.

Nov. 1999: Demonstrated four Earth Science applications at the Global Observation Information Network/Committee on Earth Observing Systems conference in Stockholm, Sweden.

Nov. 1999: Demonstrated the Virtual Collaborative Clinic (VCC) application at SuperComputing'99. This was the featured application at the NASA booth. This demonstration highlighted the importance of QoS to the VCC application.

A.3 Development of Testbed Infrastructure

The accomplishments in this section trace the development of high-bandwidth connectivity for the NREN testbed. The goal is to maintain connectivity with state-of-the-art technology. Thus bandwidth capabilities have steadily increased from 45 Mbps to current 155 Mbps with ATM over selected connections. In the near future selected NREN connectivity will be upgraded to OC-48 (2.5 Gbps) and Packet over SONET (POS).

June 1993: Program milestone (NR1: interconnect to NSFnet at 45 Mbps) completed on time.

September 1994: Program milestone (NR2: demonstrate T-3 Level 3 HPCC interconnects) completed on time.

March 1995: Sprint Lab Testing complete.

June 1995: Deployed NREN DS3 ATM services.

July 1995: IP testing completed to LeRC, LaRC, and JPL.

July 1995: Connection between ATT and Sprint achieved via CTI and NREN at LeRC.

Sept. 1995: Program milestone (NR4: demonstrate 155 Mbps NREN interconnects) completed on time. Deployed NREN OC3 ATM services (2 sites). This deployment marked the advancement of ATM technology from experimental phase to commercial availability. It accelerated commercial SONET speed ATM service by at least one year by driving the completion of the technical interface

for operational standards use between interexchange and local exchange carriers in the provisioning of future SONET-speed services.

Sept. 1995: Deployed NREN OC3 ATM services to 2 additional sites for a total of four sites completed.

Sept. 1995: AEROnet DS3 trial complete.

Oct. 1995: NASP used for IP to ATM SVCs.

Nov. 1995: Disconnected DS3s.

Nov. 1995: Deployed fifth and final site of NREN OC3 ATM services.

July - Sept. 1996: Completed test ATM technology production readiness demonstration using AEROnet as a test vehicle over the NREN-funded OC-3c (155 Mb/s) between ARC, LeRC, LaRC and JPL. This test successfully demonstrated that ATM technology is ready for deployment in meeting the AEROnet community requirements.

Nov. 1996: Established a Permanent Virtual Circuit (PVC) for NASA Internet between ARC and GSFC for testing of backbone traffic between centers.

Jan. 1998: Established connectivity to NGIX-Mid America (Chicago) enabling NREN to peer with other major high performance networks.

Dec. 1998: Completed NGIX-West implementation at ARC.

Oct. 1999: Completed OC-12 connectivity to NTON enabling NREN to deploy gigabit applications.

A.4 Administrative accomplishments

Oct. 1996: NREN project manager named.

Oct.-Nov. 1996: Reviewed ATM backbone sharing study with HPCCP, Supercomputing, AEROnet and NASA Internet representatives. Agreement to proceed with engineering design and cost sharing from ARC program offices received in partnership with NISN office.

Oct. - Nov. 1996: Next Generation Internet Concept Paper drafted by Large Scale Networking Working Group. Initiative announced by Administration. Baseline funding augmentation to NREN program approved for NGI initiative support.

Nov.- Dec. 1996: Completed NASA NREN Project draft plan for FY 1997 to FY 2002.

Dec. 1996: Developed high performance networking application selection criteria for testing and demonstrations across the NREN. Initiated application solicitation process. Application project engineer assigned to HPCCP/NREN office.

June 1997: Signed MOU with NISN at Marshall Space Flight Center.

Sept. 1997: Congress funded NGI for $85 million. Participating agencies include DARPA, NSF, NASA, NIST, and the National Library of Medicine (NLM).

Nov. 1997: Signed MOU with CISO/SCO at Glenn Research Center.

Jan. 1998: Signed MOU between NASA and Cisco Systems.

Feb. 1998: Signed MOU between NASA and Fore Systems, Inc.

March 1998: Conducted NREN/NGI retreat with other Large Scale Networking participants.

May 1998: Conducted External Review with key nationally known experts.

May 1998: Initiated interagency agreements with NSF, NIST, and DARPA.

May 1998: Initiated inter-project agreement between NREN and Earth Science Data and Information Systems Project.

July 1998: Participated in the HPCC Independent Annual Review.

Sept. 1998: Completed Interagency Agreement between NASA Ames and DARPA, documenting commitments of NREN Project Office at ARC and DARPA to collaborate in internetworking research and end-to-end support for high-performance applications across the interagency research networks.

Nov. 1998: Presented NASA advanced networking strategy and applications update to industry and academia at the interagency Panel on NGI at SuperComputing 98.

Nov. 1998: NREN Project Manager selected as co-chair of the US High Performance Network Applications Team (HPNAT).

Oct. 1999: Participated in the Presidents Information Technologies Advisory Committee (PITAC) Review.

23.2 Appendix B: Previous Program Milestones

Table 14-Previous Program Milestones

ID	L1 Milestone	Due Date	Metrics	Success Criteria
NR7	Establish next generation internetwork exchange for NASA to connect Grand Challenge universities' principal investigators to NASA high performance resources	10/98	Performance	100X increased capability to access NASA HPCC resources by Grand Challenge researchers
NR8	Demonstrate end-to-end performance improvement of Grand Challenge and/or NASA mission applications across 500 times more capable internetwork than the FY96 baseline. (Over 622 Mbps wide area network)	3/00 (changed from 9/99)	Number of applications Performance	At least 3 demos 500X end-to-end performance improvement over FY1996 baseline
NR8b	Prototype new networking technologies	9/01	Number of enabling technologies Technology evaluation, demonstrations, and reporting	At least 2 technologies (QoS, Multicasting) Provide research level demonstrations and reports
NR9	Demonstrate high performance network applications across interagency high performance testbed using NREN Infuse new network technologies enhancing applications within HPCC projects and NASA missions	9/02	Number of Applications Application demonstrations	At least 3 applications Provide inter-agency level demonstrations
NR10	Research specific middleware solutions benefiting HPCC and NASA projects	6/03 (new)	Recommendations	Provide multi-HPCC/NASA projects recommendations
NR11	Prototype acceptable recommended middleware solutions	9/04 (new)	Technology evaluation, demonstrations, and reporting	Provide research level demonstrations and reports

23.3 Appendix C: Acronyms

ACTS	Advanced Communications Technology Satellite
ARC	Ames Research Center
ATDNet	Advanced Technology Demonstration Network
ATM	Asynchronous Transfer Mode
CIC	Computing, Information, and Communications
CIO	Chief Information Officer
CISO	Computing and Interdisciplinary Systems Office (GRC)
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DREN	Defense Research and Engineering Network
EAR	Export Administration Regulations
ESnet	Energy Sciences Network
ESS	Earth and Space Sciences
FAA	Federal Aviation Administration
FOIA	Freedom of Information Act
FY	Fiscal Year
Gbps	Gigabits per second
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HEDS	Human Exploration and Development of Space
HPCC	High Performance Computing and Communications
HPCCP	High Performance Computing and Communications Program
HPNAT	High Performance Network Applications Team
IA	Interagency Agreement
IAR	Independent Annual Review
IETF	Internet Engineering Task Force
IP	Internet Protocol
ITAR	International Traffic in Arms Regulations
JET	Joint Engineering Team
JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center
LAN	Local Area Network
LaRC	Langley Research Center
LeRC	Lewis Research Center (now Glenn Research Center)
LSN	Large Scale Networking
MAGIC	Multidimensional Applications and Gigabit Internetwork Consortium
Mbps	Megabits per second
MIX	Multicast Internet eXchange
MOU	Memorandum of Understanding

MSDP	Multicast Source Discovery Protocol
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NCO	National Coordination Office
NGI	Next Generation Internet
NGIX	Next Generation Internet Exchange
NIH	National Institutes of Health
NISN	NASA Integrated Services Network
NIST	National Institute of Standards and Technology
NLM	National Library of Medicine
NREN	NASA Research and Education Network
NRT	NGI Networking Research Team
NSF	National Science Foundation
NSFnet	National Science Foundation Network
NTON	National Transparent Optical Network
OC-3	Optical Carrier-31(55 Mb/s)
OC-12	Optical Carrier-12 (622 Mb/s)
OTH	Over The Horizon
PCA	Program Commitment Agreement
PIM-SM	Protocol Independent Multicast – Sparse Mode
PITAC	President's Information Technology Advisory Committee
PMC	Program Management Council
PMO	Program Management Office
POP	Point Of Presence
PVC	Permanent Virtual Circuit
QoS	Quality of Service
R&D	Research and Development
RFC	Request for Comments
SCO	Space Communications Office
SONET	Synchronous Optical Network
SVC	Switched Virtual Circuit
TRL	Technology Readiness Level
UDP	User Datagram Protocol
vBNS	very high performance Backbone Network Service
VCC	Virtual Collaborative Clinic
VLAB	Virtual Simulation Laboratory
WAN	Wide Area Network
WBS	Work Breakdown Structure